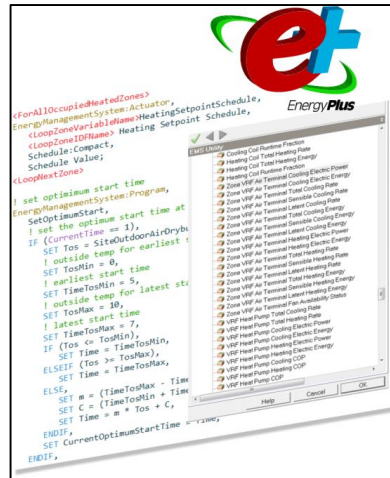


DesignBuilder scripting tools: Unlock almost unlimited flexibility to customise simulation behaviour



David Cocking MSc CEng MCIBSE MASHRAE

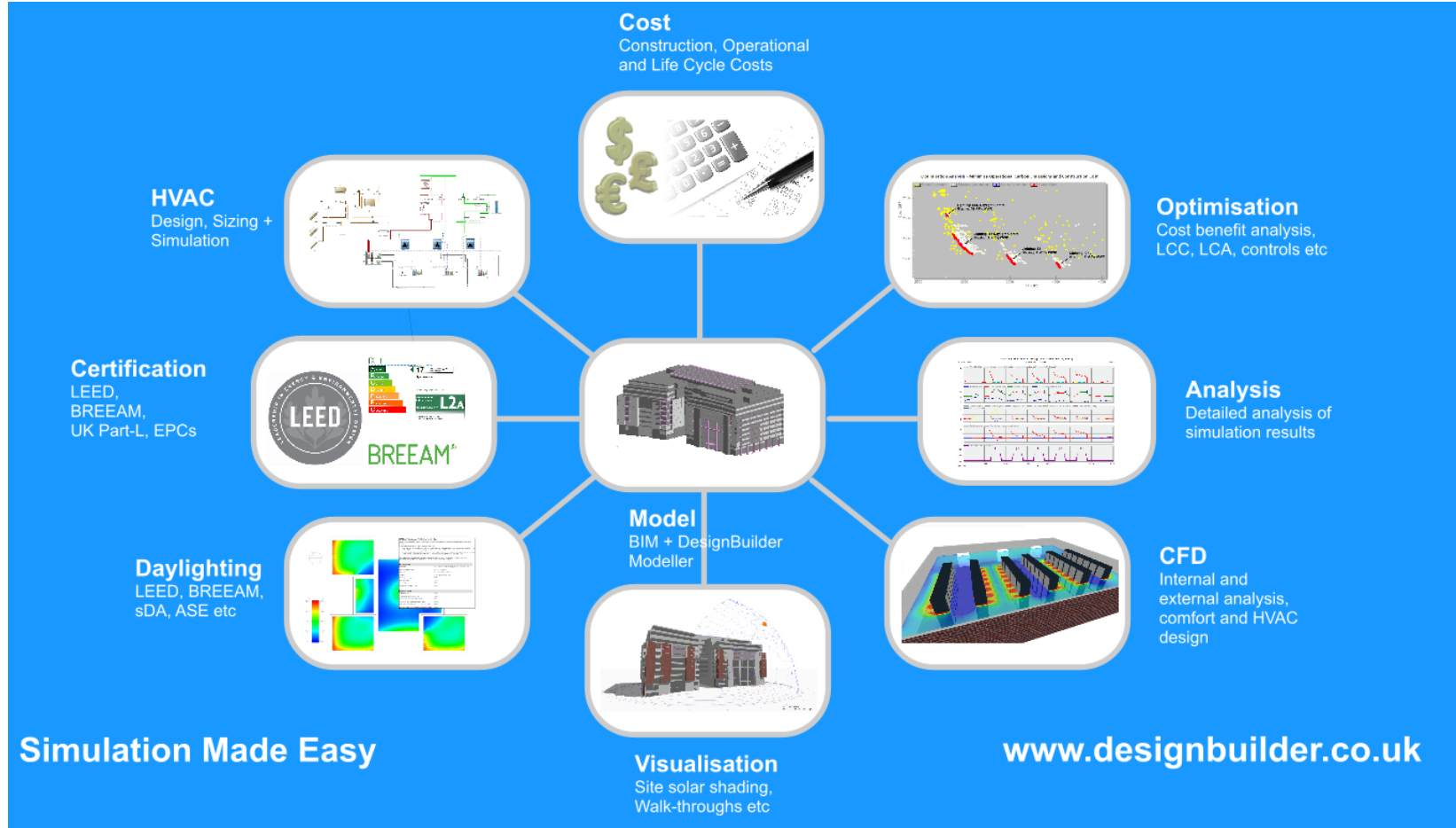
Director | DesignBuilder Software Ltd | www.designbuilder.co.uk

“Hacking Simulation” presentation content

- Introduce DesignBuilder’s scripting tools...what they are and how they can help.
- Simple example to illustrate how DesignBuilder’s scripting tools work in practise.
- Case studies showing how scripting has been used to customise simulated behaviour to meet non-standard or unusual client needs.

“Simulation Made Easy”...early, compliance or detailed modelling!

Engineers, Architects, Energy Assessors, Academic Research and Teaching



4 ways to “hack” DesignBuilder EnergyPlus simulations

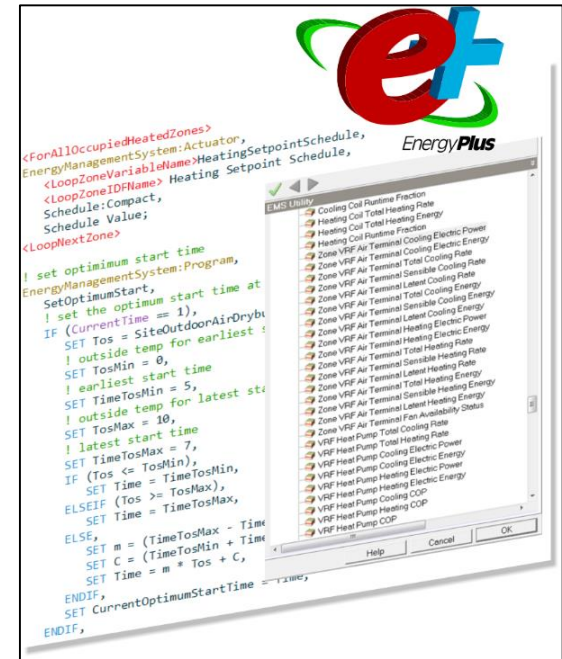
“Regular” Modellers:

- Modify (open source) EnergyPlus input data file (**IDF**)
- **EMS** – Create/edit scripts in the DesignBuilder EMS editor



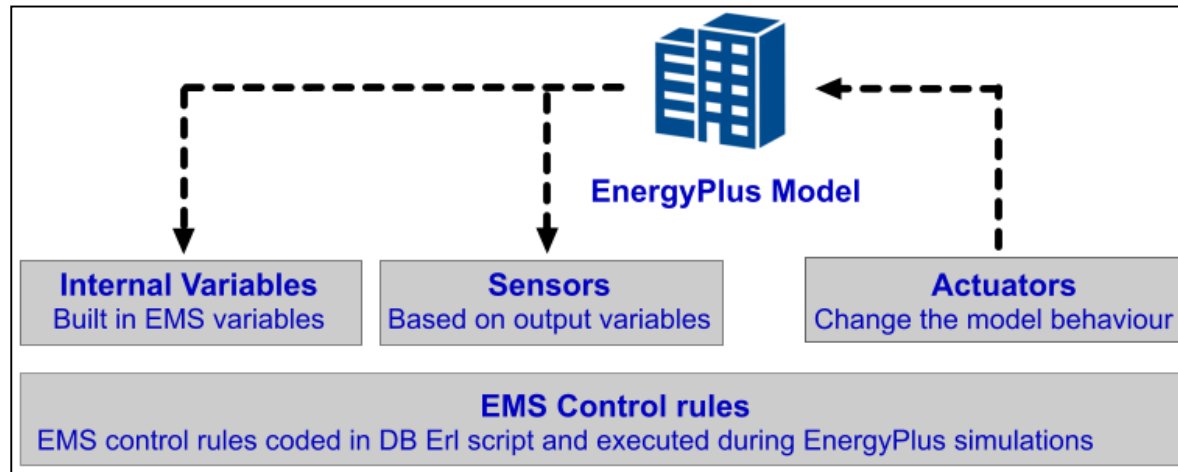
Experts:

- **FMU** – Create co-simulation applications in the DesignBuilder FMU/FMI editor
- Modify **EnergyPlus open source code**



DesignBuilder EMS: works like a BMS

1. **Sensors:** check variable value (zone air temperature, CO2 level etc.)
2. **Actuators:** overrides model settings based on sensor input to change the model behaviour at each time-step in the simulation.
3. **Results:** Custom output variables can be written to results file.
4. **Program:** manages and initiates what is called and at what frequency



Some example DesignBuilder scripting applications

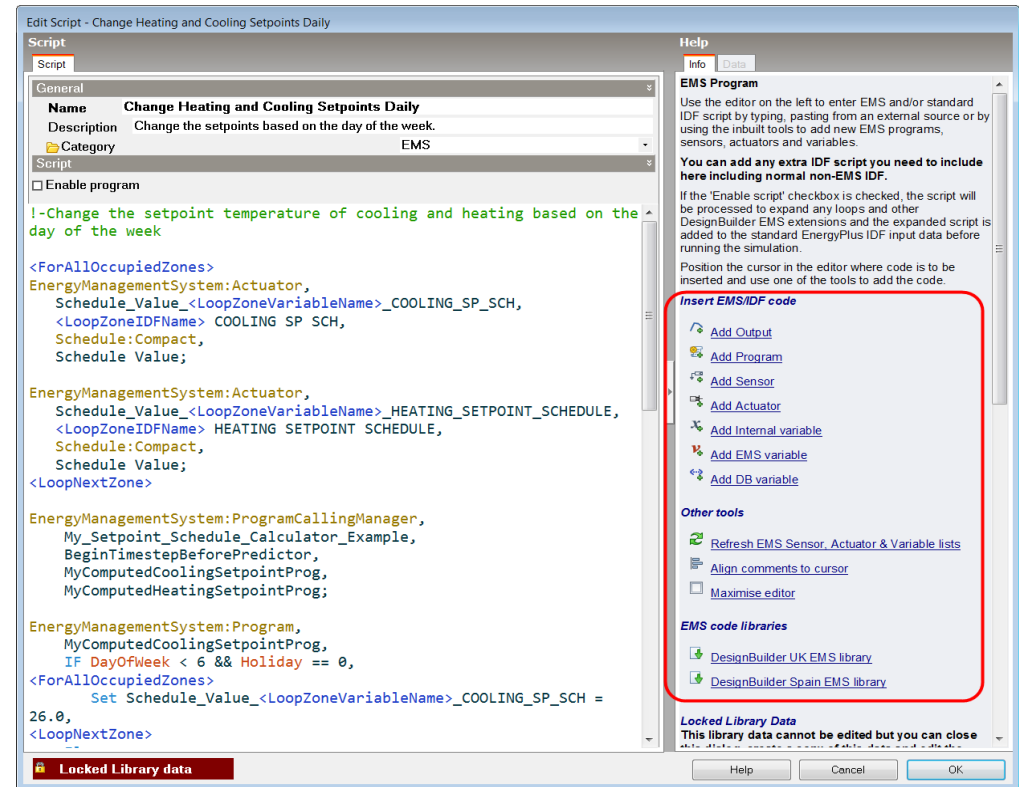
Flexibility to influence EnergyPlus simulation behaviour at each time-step using the EMS...almost limitless applications:

- Programmatic scheduling (over-ride fixed/static schedules)
- Bespoke control of HVAC systems
- Connecting different HVAC systems
- Advanced façade and natvent controls
- Outputs not normally provided in DesignBuilder or EnergyPlus
- Research...novel applications not provided by mainstream tools

DesignBuilder EMS extensions...beyond EnergyPlus

DesignBuilder includes important extensions to the standard EnergyPlus EMS system to **simplify and speed up script generation**:

- Access attribute data (setpoints, schedules etc.) direct from model data lists
- Quickly add actuators, sensors and internal variables
- Loops simplify scripts and make them portable
- Colour syntax highlighting

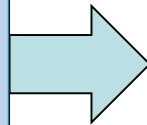


DesignBuilder's example script library

Select the Script

- CS-Script
 - BaseScript - This base script must be compiled once. It i
 - EpNet IDF find and replace - EpNet find and replace the
 - Load heating setpoints from template to model - Load he
 - MultiScript - This will call all public methods from the imp
 - SampleScript1 - All public methods in the DBScript class
 - SampleScript2 - All public methods in the DBScript class
 - SampleScript3 - EpNet find and replace thermal absorpt
 - SampleScript4 - Write report called CSVReport.csv to de
 - SampleScript5 - Load heating setpoints from an activity t
 - Simple example model report - Write report called CSVF
- EMS
 - Building Average Zone Air Temperature - Calculate buil
 - Change Heating and Cooling Setpoints Daily - Change th
 - CIBSE TM52 Reports - Generate CIBSE TM52 Reports
 - CIBSE TM59 Reports - Generate CIBSE TM59 Reports
 - CIBSE TM59 Ventilation temperature control enhance
 - CO2 control (On/Off) - Control external windows in nat ver
 - CO2 control (Proportional) - Vary external window openin
 - L5 HR Bypass IdealLoads - Bypass heat recovery when
 - L5 HR Bypass ZoneVentilation - Bypass heat recovery v
 - Multiple State Electrochromic Glass with Individual Sens
 - Multiple State Electrochromic Glass with Sensor Groups**
 - Optimum start heating control (domestic) - Override heati
 - Optimum start heating control (non-domestic) - Override t
 - Set external heat transfer coefficient - Set the heat transfe
- Python-Script
 - Python-Script Example - Test the Python-Script interface

Buttons: +, Cancel, Sort, OK



Edit Script - Multiple State Electrochromic Glass with Sensor Groups

Script

General

Name: **Multiple State Electrochromic Glass with Sensor Groups**

Description: Simulate multiple state electrochromic glass, with each window belonging to a sensor group.

Category: EMS

Script

Enable program

```

!-Multiple state electrochromatic windows with sensor groups
<ForAllElectrochromicSensorWindows>
!-<LoopSensorWindowIDFName> Sensor
EnergyManagementSystem:Sensor,
  <LoopSensorWindowVariableName>_Reference_Sensor,
  <LoopWindowIDFName>,
  Surface Outside Face Incident Solar Radiation Rate per Area;

<If LoopWindowAttribute InternalBlindControlMultipleStateElectrochromic = 2
Then>
EnergyManagementSystem:Sensor,
  <LoopWindowVariableName>_Heating_Load,
  <LoopWindowZoneIDFName>,
  Zone Air System Sensible Heating Rate;
<endif>

<If LoopWindowAttribute InternalBlindControlMultipleStateElectrochromic = 3
Then>
EnergyManagementSystem:Sensor,
  <LoopWindowVariableName>_Cooling_Load,
  <LoopWindowZoneIDFName>,
  Zone Air System Sensible Cooling Rate;
<endif>

<If LoopWindowAttribute InternalBlindControlMultipleStateElectrochromic = 4
Then>
EnergyManagementSystem:Sensor,

```

Help

Info Data

EMS Program

Use the editor on the left to enter EMS and/or standard IDF script by typing, pasting from an external source or by using the inbuilt tools to add new EMS programs, sensors, actuators and variables.

You can add any extra IDF script you need to include here including normal non-EMS IDF.

If the 'Enable script' checkbox is checked, the script will be processed to expand any loops and other DesignBuilder EMS extensions and the expanded script is added to the standard EnergyPlus IDF input data before running the simulation.

Position the cursor in the editor where code is to be inserted and use one of the tools to add the code.

Insert EMS/IDF code

- Add Output
- Add Program
- Add Sensor
- Add Actuator
- Add Internal variable
- Add EMS variable
- Add DB variable

Other tools

- Refresh EMS Sensor, Actuator & Variable lists
- Align comments to cursor
- Maximise editor

EMS code libraries

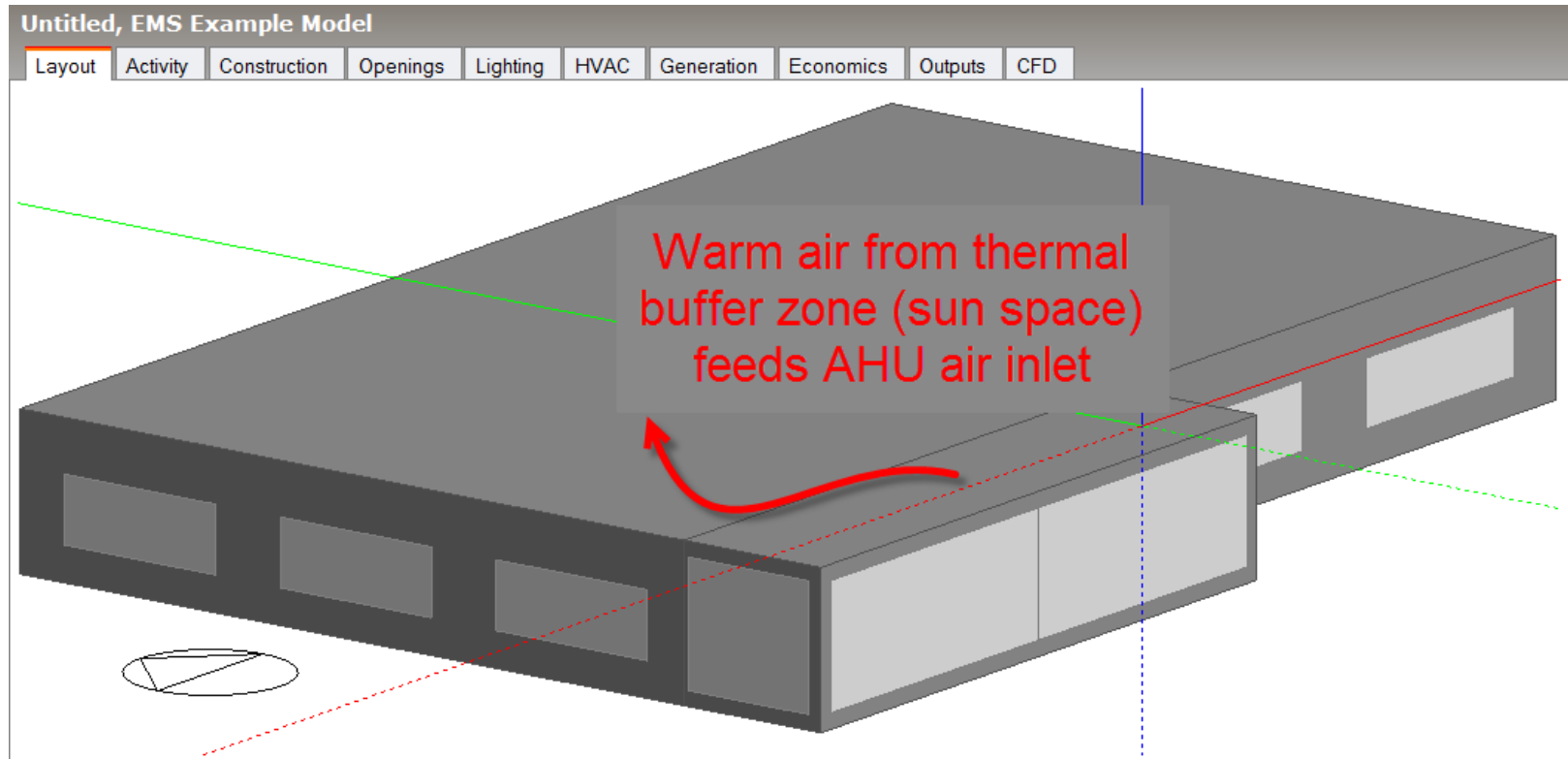
- DesignBuilder UK EMS library

Buttons: Help, Cancel, OK

Locked Library data

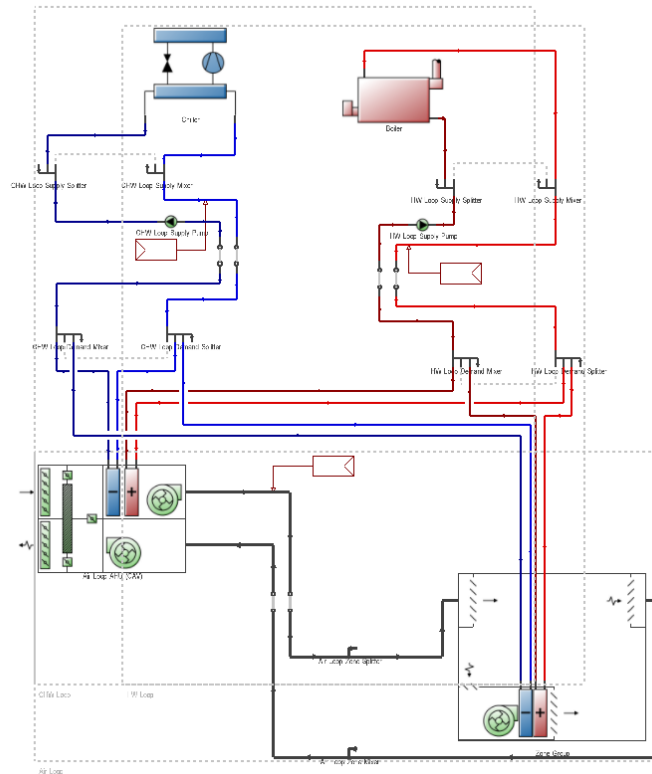
Simple AHU pre-heat example

Pre-heat or pre-cool AHU inlet air from sun space, earth tube etc



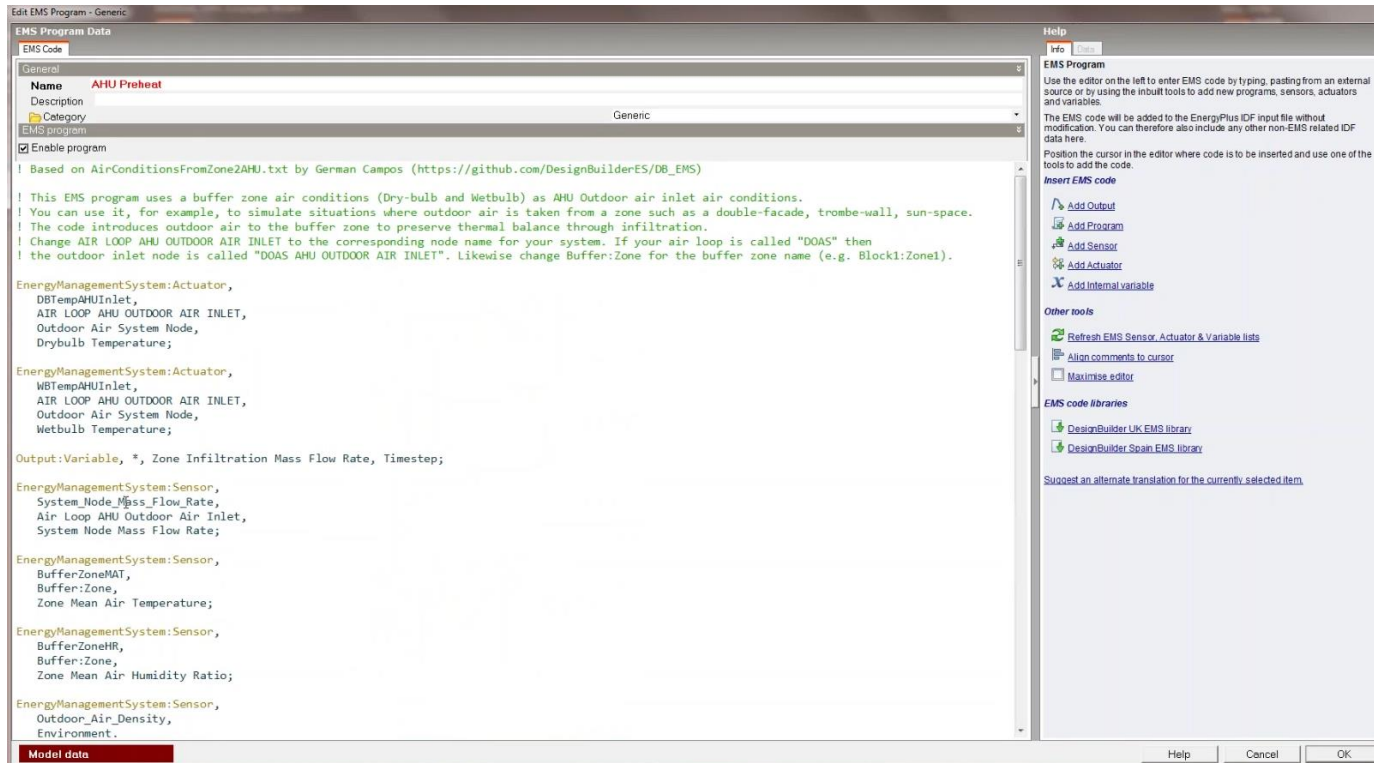
Simple AHU example...HVAC system

Zone FCUs served by AHU with CHW and HW coils...but no AHU pre-heat



Simple AHU pre-heat example...script

Script links pre-heat zone air to AHU inlet to over-ride standard HVAC setup



The screenshot shows the 'Edit EMS Program - Generic' window. The 'Name' field is 'AHU Preheat' and the 'Category' is 'Generic'. The 'Enable program' checkbox is checked. The main text area contains the following script:

```

! Based on AirConditionsFromZone2AHU.txt by German Campos (https://github.com/DesignBuilderES/DB_EMS)

! This EMS program uses a buffer zone air conditions (Dry-bulb and Wetbulb) as AHU Outdoor air inlet air conditions.
! You can use it, for example, to simulate situations where outdoor air is taken from a zone such as a double-facade, trombe-wall, sun-space.
! The code introduces outdoor air to the buffer zone to preserve thermal balance through infiltration.
! Change AIR LOOP AHU OUTDOOR AIR INLET to the corresponding node name for your system. If your air loop is called "DOAS" then
! the outdoor inlet node is called "DOAS AHU OUTDOOR AIR INLET". Likewise change Buffer:Zone for the buffer zone name (e.g. Block1:Zone1).

EnergyManagementSystem:Actuator,
  DBTempAHUInlet,
  AIR LOOP AHU OUTDOOR AIR INLET,
  Outdoor Air System Node,
  Drybulb Temperature;

EnergyManagementSystem:Actuator,
  WBTempAHUInlet,
  AIR LOOP AHU OUTDOOR AIR INLET,
  Outdoor Air System Node,
  Wetbulb Temperature;

Output:Variable, *, Zone Infiltration Mass Flow Rate, Timestep;

EnergyManagementSystem:Sensor,
  System Node Mass Flow Rate,
  Air Loop AHU Outdoor Air Inlet,
  System Node Mass Flow Rate;

EnergyManagementSystem:Sensor,
  BufferZoneMAT,
  Buffer:Zone,
  Zone Mean Air Temperature;

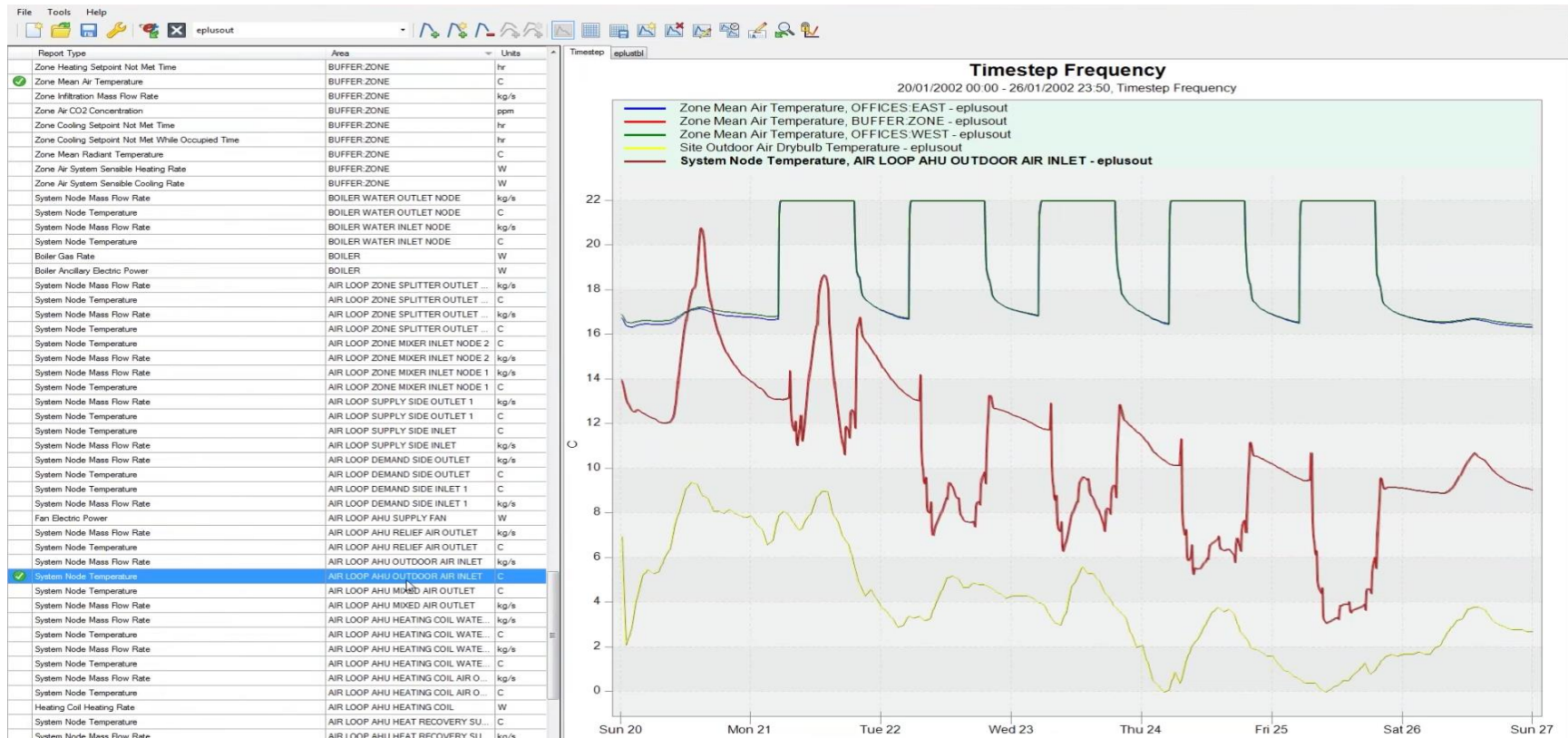
EnergyManagementSystem:Sensor,
  BufferZoneHR,
  Buffer:Zone,
  Zone Mean Air Humidity Ratio;

EnergyManagementSystem:Sensor,
  Outdoor_Air_Density,
  Environment.
  
```

The right-hand side of the window contains a 'Help' panel with instructions on how to use the editor and a list of 'Insert EMS code' options like 'Add Outlet', 'Add Program', 'Add Sensor', 'Add Actuator', and 'Add Internal variable'. At the bottom, there are 'Model data', 'Help', 'Cancel', and 'OK' buttons.

Simple AHU pre-heat example...results

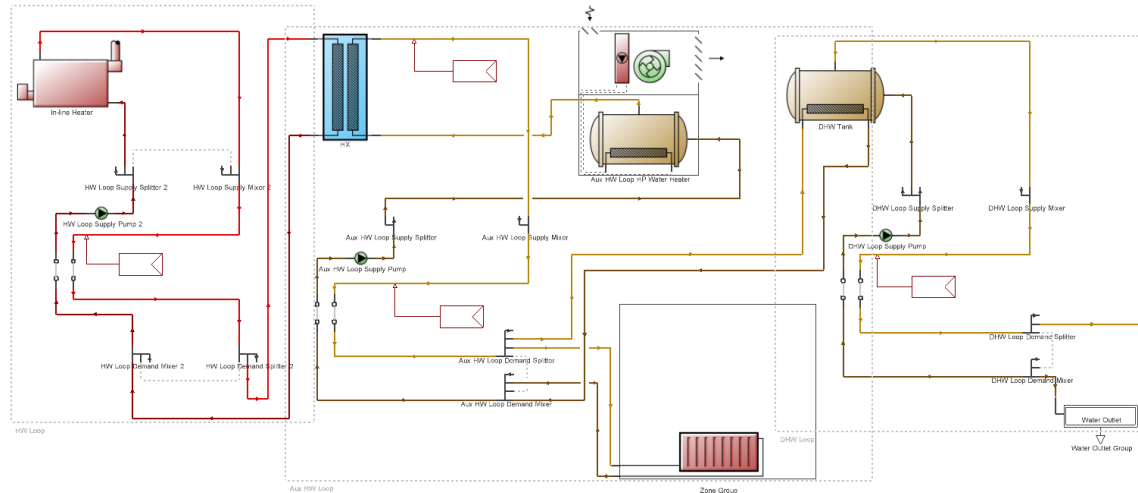
Results show that the AHU air inlet temperature matches buffer zone (not OAT)



Hybrid ASHP - EMS case study

(Project with Delta-ee and Dr Dave Kane)

Range of LT/HT/Hybrid ASHP systems modelled for different dwelling types.



- Specific manufacturers systems modelled in detail using EMS to provide:
 - Weather compensation controls for HW supply temperature
 - Tailored optimum start for both morning and evening heating periods
 - Custom control over electric boost availability to maximise efficiency

Hybrid ASHP – Example part of EMS script

- Weather compensation script to replace simple ASHP supply temperature schedule, accounting for DHW operation.
- Script minimises the HP supply temperature unless the DHW system is operating or outdoor temperature drops.
- This part of the EMS script is a good example of using SET, IF and ELSE statements to dynamically control equipment based on other variables

```
! override "ASHP outlet setpoint temperature" schedule with weather compensation
EnergyManagementSystem:Program,
  SetASHPSupplyTempSp,
  SET Tos = Site_Outdoor_Air_Drybulb_Temperature,
  ! outside temp for max setpoint
  SET TosMin = 0,
  ! max setpoint
  SET TspTosMin = 55,
  ! outside temp for min setpoint
  SET TosMax = 15,
  ! min setpoint
  SET TspTosMax = 40,
  ! set setpoint based on outside air temperature and DHW operation
  IF (DHWTankSourceSideHeatTransferRate > 10),
    ! use high temperature output when DHW is operating
    SET Tsp = TspTosMin,
  ELSEIF (Tos <= TosMin),
    ! very code outside, use highest supply temperature
    SET Tsp = TspTosMin,
  ELSEIF (Tos >= TosMax),
    ! warm outside, use lowest supply temperature
    SET Tsp = TspTosMax,
  ELSE,
    ! interpolate
    SET m = (TspTosMax - TspTosMin) / (TosMax - TosMin),
    SET C = (TspTosMin + TspTosMax - m * (TosMin + TosMax)) / 2,
    SET Tsp = m * Tos + C,
  ENDIF,
  ! actuate the supply setpoint temperature
  SET ASHPSupplyTempSp = Tsp;
```

UCL IEDE Case Study: 'Total Performance'

Project to investigate 'total performance': finding ways to minimise energy demand and carbon emissions **whilst safeguarding occupant health, wellbeing and productivity**



Acknowledgements:

UCL IEDE:

Nishesh Jain, Esfand Burman, Sam Stamp,
Clive Shrubsole, Dejan Mumovic, Michael
Davies

DesignBuilder:

Andy Tindale

More information: www.ucl.ac.uk/bartlett/environmental-design/research/total-performance-low-carbon

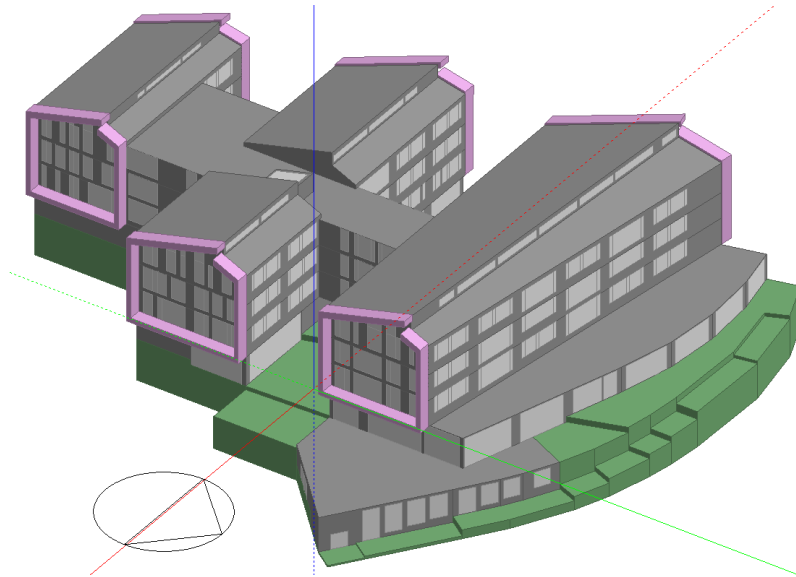
UCL IEDE case study building

Public sector natvent open-plan office building in Keynsham



Stage 1: Calibrating the energy model

‘Performance gap’; measured **energy** results worse than predicted using the designer’s typical schedules, weather data etc: **+107% gas and +46% electric**



DesignBuilder model

Criteria	Designed (kWh/m ²)	Actual (kWh/m ²)	Diff (%)
Total Energy (Gas + Elec)	14 + 57	29 + 68	+37%
Heating & Hot Water (Gas+Elec)	13.9+5.0	28.85+0	+53%
Cooling energy (Elec)	0.17	0	NA
Pumps + Mech Vent (Elec)	1.73	9.97	+478%
Int. Lighting (Elec)	5.00	11.13	+123%
Ext. Lighting (Elec)	1.11	0	NA
Small Power (Elec)	16.49	28.89	+75%
Catering (Elec)	0.85	1.60	+89%
Server Elec (Elec)	26.42	15.19	-42%
Lifts (Elec)	0.28	0.72	+159%
PV Generation (Elec)	31.22	30.43	-3%
Net Energy (Gas + Elec)	14 + 26	29 + 38	+67%

EMS used in the calibration process

EMS used to calibrate the DesignBuilder model more efficiently by modifying key operational data to match the actual building:

```

EnergyManagementSystem:Program,
KTHIacEnergy,
! add program code
IF (DayOfWeek >= 2) && (DayOfWeek <= 6) && (Hour >= 7) && (Hour < 8),
  Set Schedule_Value_KTH_OFFICE_OPENOFF_OCC = 0.15,
  Set Schedule_Value_KTH_OFFICE_OPENOFF_LIGHT = 0.15,
  Set Schedule_Value_KTH_OFFICE_OPENOFF_EQUIP = 0.35,
  Set Schedule_Value_KTH_OFFICE_OPENOFF_SERVER = 0.35,
ElseIf (DayOfWeek >= 2) && (DayOfWeek <= 6) && (Hour >= 8) && (Hour < 9),
  Set Schedule_Value_KTH_OFFICE_OPENOFF_OCC = 0.5,
  Set Schedule_Value_KTH_OFFICE_OPENOFF_LIGHT = 0.4,
  Set Schedule_Value_KTH_OFFICE_OPENOFF_EQUIP = 0.7,
EnergyManagementSystem:Actuator,
Schedule_Value_KTH_OFFICE_OPENOFF_LIGHT,
KTH_OFFICE_OPENOFF_LIGHT,
Schedule:Compact,
Schedule:Value;

EnergyManagementSystem:Actuator,
Schedule_Value_KTH_OFFICE_OPENOFF_OCC,
KTH_OFFICE_OPENOFF_OCC,
Schedule:Compact,
Schedule:Value;

EnergyManagementSystem:Actuator,
Schedule_Value_KTH_OFFICE_OPENOFF_EQUIP,
KTH_OFFICE_OPENOFF_EQUIP,
Schedule:Compact,
Schedule:Value;

EnergyManagementSystem:Actuator,
Schedule_Value_KTH_OFFICE_OPENOFF_SERVER,
KTH_OFFICE_OPENOFF_SERVER,
Schedule:Compact,
Schedule:Value;
  
```

Occupancy/lighting
patterns/schedules

```

EnergyManagementSystem:Actuator,
Schedule_Value_KIN_INDOOR_TEMP_FOR_NAT_VENT_ALWAYS_18/23,
KIN_INDOOR_TEMP_FOR_NAT_VENT_ALWAYS_18/23,
Schedule:Compact,
Schedule:Value;

!forallDCcupid@heatedZones)
EnergyManagementSystem:Actuator,
Schedule_Value_cLoopZoneVariableName_HEATING_AVAILABILITY_SCH,
cLoopZoneIDName HEATING_AVAILABILITY_SCH,
Schedule:Compact,
Schedule:Value;

EnergyManagementSystem:Actuator,
Schedule_Value_cLoopZoneVariableName_HEATING_SETPOINT_SCHEDULE,
cLoopZoneIDName HEATING_SETPOINT_SCHEDULE,
Schedule:Compact,
Schedule:Value;

EnergyManagementSystem:Program,
HyComputeNatVentProg,
!forallDCcupid@heatedZones)
Set Schedule_Value_cLoopZoneVariableName_HEATING_AVAILABILITY_SCH = 1,
!loopNextZone)
!forallDCcupid@heatedZones)
IF (Month == 1),
  IF (DayOfWeek >= 2) && (DayOfWeek <= 6) && (Hour >= 8) && (Hour < 19),
    Set Schedule_Value_cLoopZoneVariableName_HEATING_SETPOINT_SCHEDULE = 19,
  Else,
    Set Schedule_Value_cLoopZoneVariableName_HEATING_SETPOINT_SCHEDULE = 18,
  EndIf,
EndIf,
  
```

Natvent controls
and set points

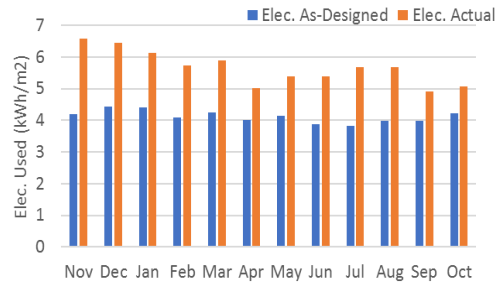
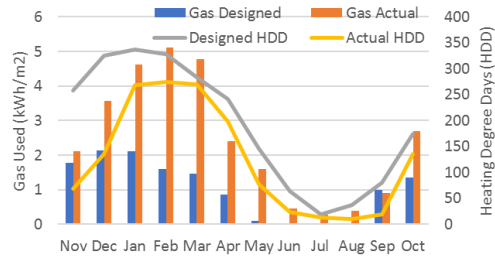
```

EnergyManagementSystem:Program,
KTHPumpsVentEnergy,
! add program code
IF (DayOfWeek >= 2) && (DayOfWeek <= 6) && (Hour >= 7) && (Hour < 8),
  Set pd = 0.35,
ElseIf (DayOfWeek >= 2) && (DayOfWeek <= 6) && (Hour >= 8) && (Hour < 9),
  Set pd = 0.7,
ElseIf (DayOfWeek >= 2) && (DayOfWeek <= 6) && (Hour >= 9) && (Hour < 12),
  Set pd = 1,
ElseIf (DayOfWeek >= 2) && (DayOfWeek <= 6) && (Hour >= 12) && (Hour < 14),
  Set pd = 0.9,
ElseIf (DayOfWeek >= 2) && (DayOfWeek <= 6) && (Hour >= 14) && (Hour < 17),
  Set pd = 1,
ElseIf (DayOfWeek >= 2) && (DayOfWeek <= 6) && (Hour >= 17) && (Hour < 18),
  Set pd = 0.7,
ElseIf (DayOfWeek >= 2) && (DayOfWeek <= 6) && (Hour >= 18) && (Hour < 19),
  Set pd = 0.45,
Else,
  Set pd = 0.25,
EndIf,
IF (Month == 4),
  Set pm = 0.5,
ElseIf (Month == 9),
  Set pm = 0.25,
ElseIf (Month == 10),
  Set pm = 0.25,
ElseIf (Month == 1) || (Month == 11) || (Month == 12),
  Set pm = 1.5,
Else,
  Set pm = 1,
EndIf,
Set Schedule_Value_KTH_OFFICE_OPENOFF_PUMPS = pd * pm,
  
```

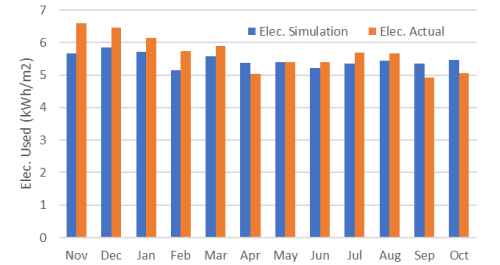
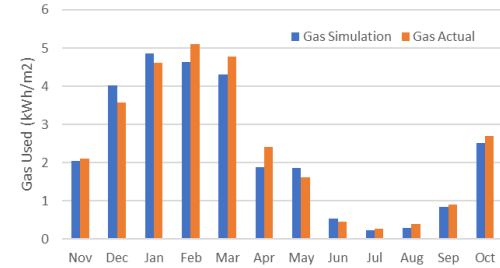
HVAC pump
operation

Calibrated model results

Model calibrated to CV(RSME) and NMBE tolerances of <5% error:



Initial gas & elec results



Calibrated gas & elec results

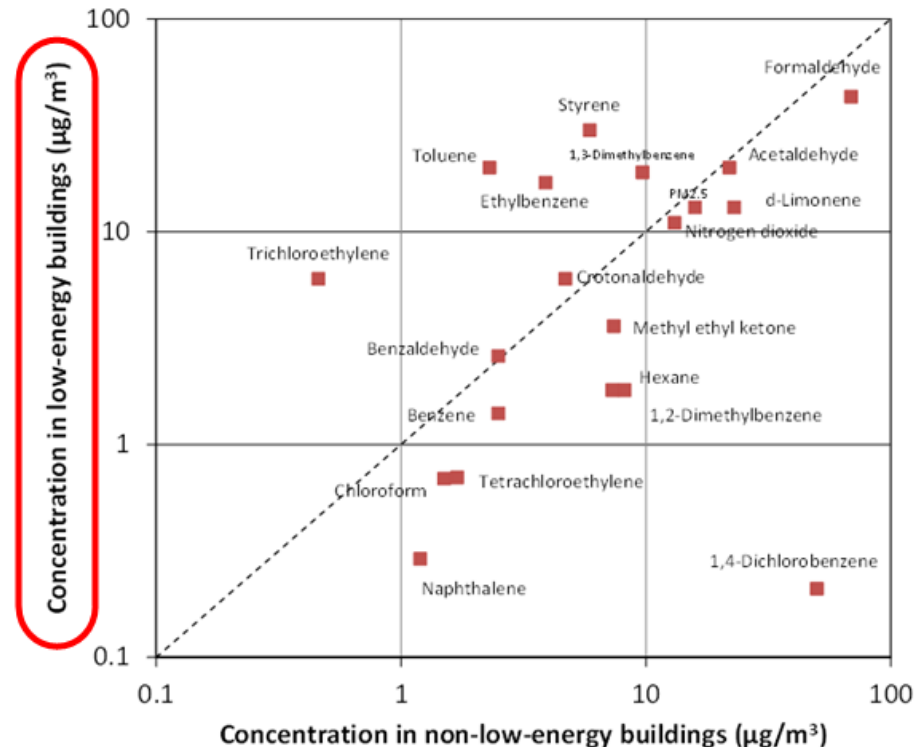
Stage 2: Focus on Health and Wellbeing

The ‘tension’ between low energy and good IAQ

IEA Annex 68 report:

Finds higher pollutant concentrations in low-energy buildings

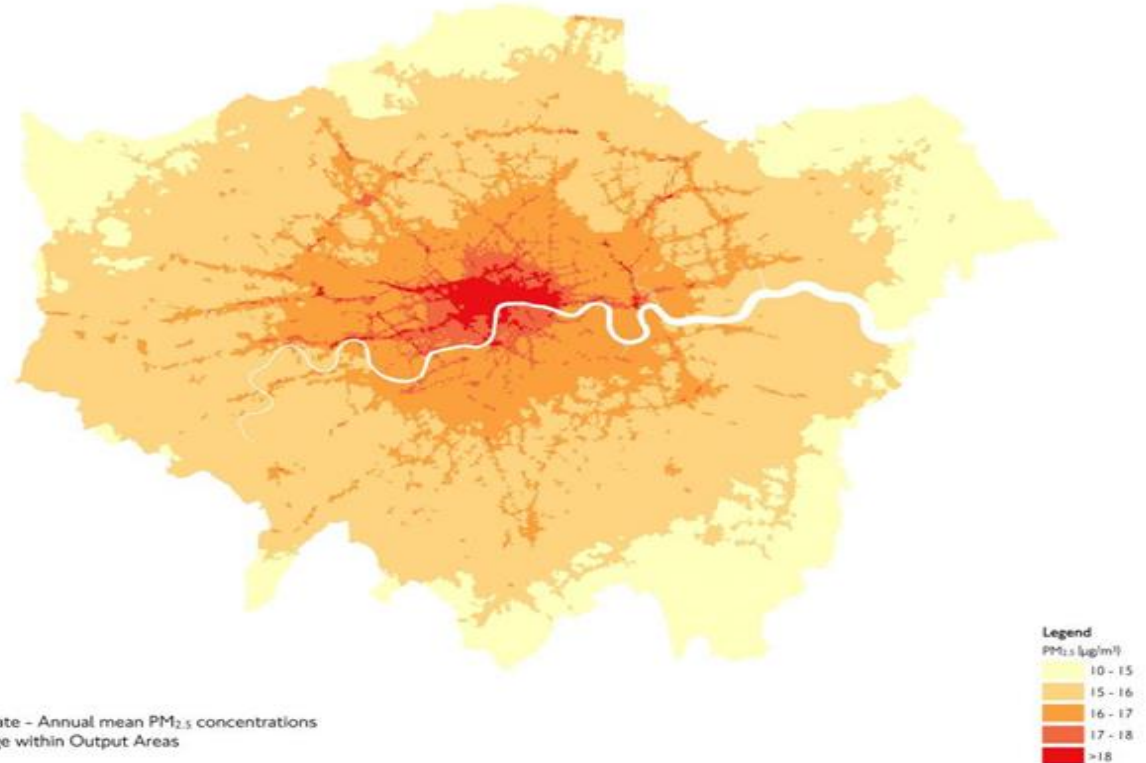
Recommends that key pollutants such as PM2.5 should be measured and kept within limits
...not just CO2!



Health and Wellbeing: PM_{2.5} concentrations

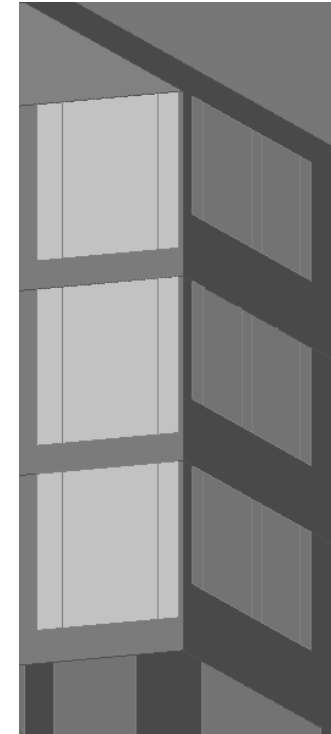
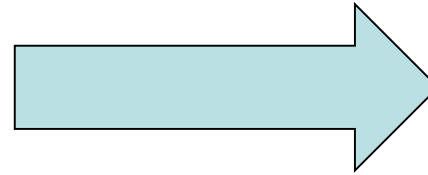
London PM_{2.5} values exceed WHO guidelines and sometimes EU limits

- EU legal limit (annual mean):
25 $\mu\text{g}/\text{m}^3$
- WHO guideline limit (annual mean):
10 $\mu\text{g}/\text{m}^3$
- Estimated that difference between EU and WHO limits doubles risk of early death



With IAQ in mind: natvent strategy

Vents controlled on CO2 by BMS...CO2 good IAQ proxy but perhaps not in isolation?



Improved IAQ control strategy using EMS

EMS used to import external measured pollutant data, sense both internal CO2 and PM2.5 and modify control strategy, then generate custom output reports

```

EnergyManagementSystem:Program,
  CO2WindowControl,
<ForAllExternalWindows>
  ! on/off control of window opening factor
  If <LoopWindowVariableName>Air_CO2_Concentration > 1500,
    If Schedule_Value_PM25 < 0.04,
      Set Venting_Opening_Factor_<LoopWindowVariableName> = 1,
    Elseif Schedule_Value_PM25 >= 0.04,
      Set Venting_Opening_Factor_<LoopWindowVariableName> = 0,
    Endif,
  Else,
    Set Venting_Opening_Factor_<LoopWindowVariableName> = 0,
  Endif,
<LoopNextWindow>
.
....._Windows>
EnergyManagementSystem:Sensor,
  <LoopWindowVariableName>Air_CO2_Concentration,
  <LoopWindowZoneIDFName>,
  Zone Air CO2 Concentration;

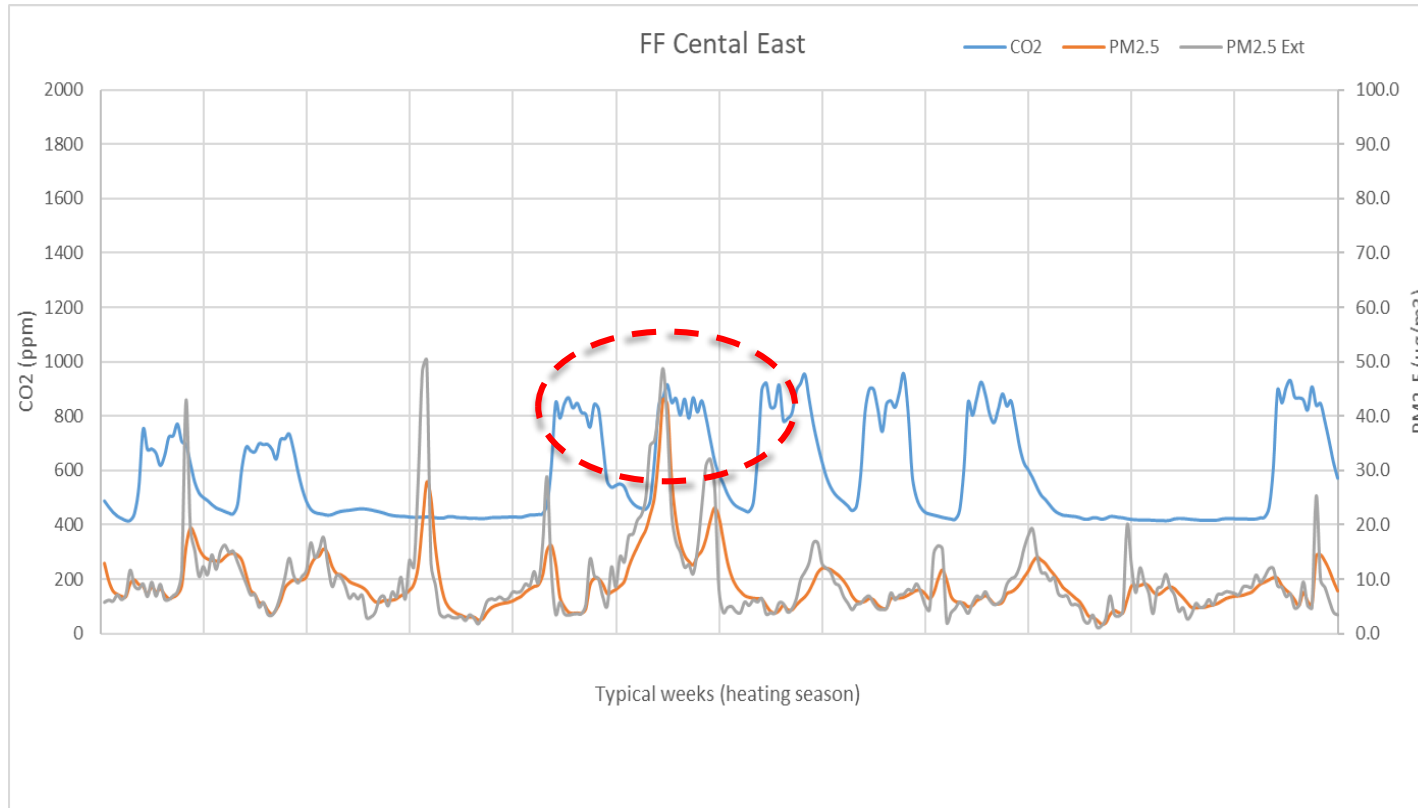
EnergyManagementSystem:Actuator,
  Venting_Opening_Factor_<LoopWindowVariableName>,
  <LoopWindowIDFName>,
  AirFlow Network Window/Door Opening,
  Venting Opening Factor;
<LoopNextWindow>

! extra outputs for viewing in the results viewer
<If BuildingAttribute HourlyOutput = 1 Then>
Output:Variable, *, Zone Air CO2 Concentration, hourly;
Output:Variable, *, Zone Air Generic Air Contaminant Concentration, hourly;
<Endif>
<If BuildingAttribute TimesteplyOutput = 1 Then>
Output:Variable, *, Zone Air CO2 Concentration, timestep;
Output:Variable, *, Zone Air Generic Air Contaminant Concentration,timestep;
<Endif>

```


IAQ control strategy with high CO2 set point

Standard CO2 control: vents open at 1000 PPM: low CO2, high ACH and PM2.5



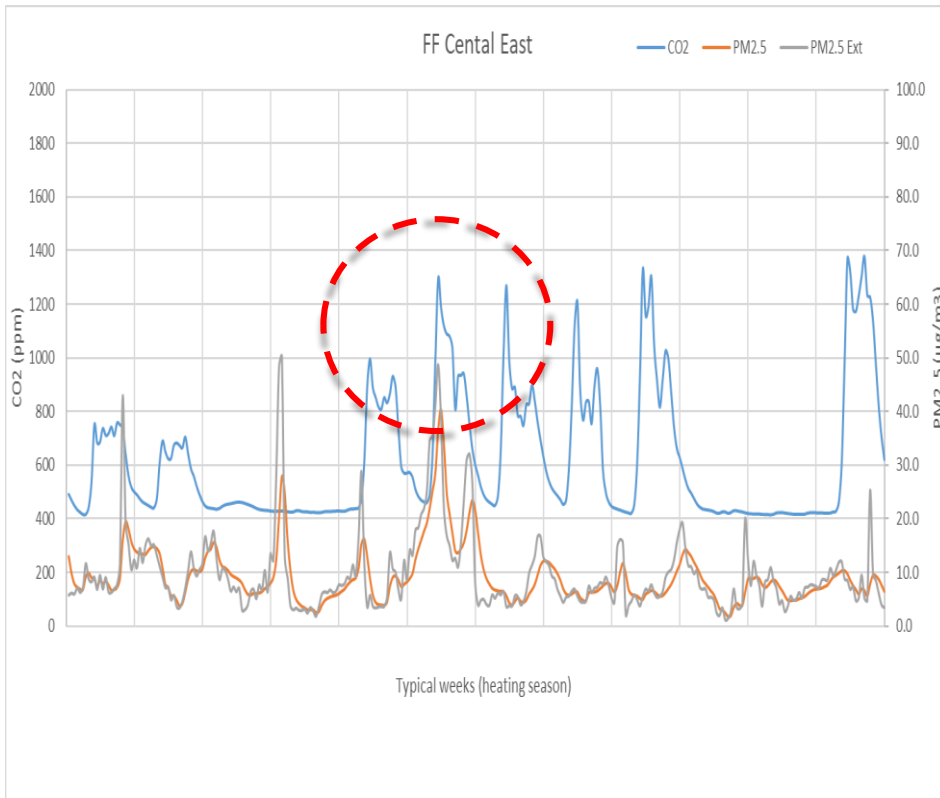
CO₂ set point
1000 ppm

Peak PM_{2.5}:
above 40 $\mu\text{g}/\text{m}^3$

Energy use
(heating):
145 Wh/m²/day

Holistic IAQ control strategy requires EMS

Revised control strategy: relax CO₂ set point, close vents if outdoor PM_{2.5} high



- CO₂ set point increased to 1500 PPM
- Close vents if outdoor PM_{2.5} > threshold
- Indoor PM levels maintained below outdoor levels
- Peak PM_{2.5}: now below 40 µg/m³
- Energy use (heating): 105 Wh/m²/day
- 28% reduction in heating energy due to relaxation of CO₂ limit

DesignBuilder scripting tools: Unlock almost unlimited flexibility to customise simulation behaviour

www.DesignBuilder.co.uk for more information

David Cocking MSc CEng MCIBSE MASHRAE

Director | DesignBuilder Software Ltd | www.designbuilder.co.uk